THE USE OF TABLETPCS AND GEOSPATIAL TECHNOLOGIES FOR PAVEMENT EVALUATION AND MANAGEMENT AT DENVER INTERNATIONAL AIRPORT

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ABSTRACT

Denver International Airport (DEN) is performing a comprehensive pavement evaluation of the all the airfield pavements. DEN's use of geospatial technologies in the pavement evaluation and pavement management has reached a new level of sophistication never before achieved. The comprehensive use of TabletPCs and GPS for distress mapping, photographic documentation, core sampling, structural evaluation, and mapping of legacy construction data has been unprecedented and very productive. DEN is using eight TabletPCs with GPS receivers to collect in GIS format a mapping of all distresses on the estimated 170,000 concrete slabs of pavement. The entire airport will be mapped in three months time. The airport is also taking georeferenced photographs at many locations to provide representative photographs of distresses observed. DEN is using the TabletPCs and GIS data to plan the locations selected for coring, field locate the cores, clear the site for utilities, and track the core test data. TabletPCs are being used to record directly into GIS format archived construction records for date of concrete pour, lot number, lot test results, mix design, and type of construction. The data will then be used to compare shrinkage cracking and other distress distributions with weather and contractor data using HIPERPAV software. The pattern of shrinkage and map cracking that was mapped in the GIS shows a very high correlation to construction lane rather than a correlation to aircraft traffic or pavement deicer. DEN is using the Rolling Dynamic Deflectometer (RDD) and HWD to evaluate the structural capacity of the pavements. All the test data is being georeferenced in the pavement management system database for further analysis. Approximately 125 miles of continuous deflection data is available for evaluation in the GIS.

INTRODUCTION

Denver International Airport (DEN) has embarked on a comprehensive pavement evaluation program and update to the existing pavement management system. DEN has over 4 million square yards of concrete airfield pavement constructed in 1992-1993 before the airport opening in 1995. With the addition of two new deicing pads, a crossfield taxiway, an expanded cargo apron and a new 16,000 foot long international runway system all constructed since the airport's opening, DEN now has over 6 million square yards of concrete airfield pavement in service in a harsh freeze thaw environment.

The Colorado Springs Municipal Airport discovered that their longest runway, constructed only 2 years before DEN's had to be replaced because of concrete durability problems related to alkali silica reaction (ASR), possibly exacerbated by the use of deicing chemicals. Officials at DEN decided that a comprehensive pavement evaluation was needed of all its airside concrete pavements, since there was a possibility that similar aggregate sources could have been used. In 2006, DEN selected DMJM Aviation to lead the pavement evaluation that would use geospatial technologies to a greater extent than any previous comprehensive pavement evaluation. All data collected during the pavement evaluation process would then be used in the continuing geospatial pavement management system.

With the uncertainty of AIP funding from the FAA, DEN, like most airports, is interested in optimizing the available funding in the maintenance and repair of critical airfield infrastructure.

Deteriorating concrete can create foreign object debris (FOD) that can be ingested by jet engines causing millions of dollars in damage. The additional problem DEN faces that is unlike any other airport, is that 4+ million square yards of airside concrete pavement is all the same age. Therefore, under similar usage, weather, etc. a systemic deterioration problem could cause multiple major failures throughout the airfield system, and at some point, create unacceptable restrictions in airfield utilization.

The GAPEMS, through the remaining life analysis, will give DEN the ability to identify current distresses, their causes and history, and predict their rate of deterioration. This information will then be manipulated to identify areas of various priorities and likely repair or replacement requirements. Having this information will allow DEN to predict annual funding requirements for pavement maintenance, repair and replacement with confidence. The information can also be used to make repair versus replacement decisions in order to level out the year to year budget for pavement maintenance.

GEOSPATIAL TECHNOLOGIES FOR PAVEMENT EVALUATION

The use of geographical information systems (GIS) with pavement management information systems (PMIS) is not new for airports or highway systems. Wisconsin Department of Transportation [1] published one of the first reports describing the use of GIS for highway pavement management in 1990. The Federal Highway Administration [2] through workshops and sponsor of research projects such as NCRRP 20-27 encouraged the use of GIS for pavement management. The Federal Aviation Administration has been slower to encourage GIS use. However, authors such as Schwartz [3] and McNerney [4] offered in the 1990s methods for airfield pavement management using GIS.

What is new for airport pavement management is that the technologies of GPS and computer software have made it easy and affordable to both collect geospatial data for pavement evaluation in the field and to revolutionize the way that pavement management is carried out at airports. The FAA in its advisory circular promoted the MicroPAVER software developed for the US Air Force [5]. However, MicroPAVER relies on the same method of data collection of distress data as the original 1970s PAVER program developed for mainframe computers when computer memory was so limited that data was reduced into a single pavement condition index (PCI) for sample sections. Fortunately, computer technology and computer memory is so cheap that new methods of geospatial mapping of distress are faster and cheaper to collect, provide better data accuracy, and the resulting data are better for pavement evaluation.

Denver International Airport recognized the need to perform a faster and more comprehensive pavement evaluation of the airfield pavements. Denver's needs included keeping daylight runway closures limited to three hour periods scheduled in advance, a comprehensive evaluation of concrete durability and pavement deicing, and a structural evaluation of the pavements. Denver had previously sampled pavement distress data with geospatial locations in 2000, however due to staffing shortages pavement maintenance and management was accomplished with manual methods and paper maps rather than using the GIS system.

The innovative program of geospatial airfield pavement evaluation and pavement management system (GAPEMS) for Denver International airport was developed by DMJM Aviation. The complexity in geospatial technologies as well the scope and magnitude of the pavement evaluation makes this GAPEMS implementation one of the most unique, challenging and comprehensive pavement management systems. Some of the innovations of the GAPEMS implementation for pavement evaluation at DEN include the following:

- Distress mapping of over 150,000 concrete slabs using WAAS enabled GPS and tabletPCs.
- Georeferencing over 6,000 photographs of pavement distresses.
- Using a tabletPC to georeference 3,600 areas representing individual concrete pours.
- Conducting over 125 miles of continuous deflection testing and displaying in GIS.
- Using tabletPCs and geospatial pavement distress data to locate, clear utilities, core and track the testing of over 200 core samples.

Distress Mapping with TabletPC and GPS

One of the biggest problems with the Pavement Condition Index (PCI) pavement rating system is the labor and time required to perform the inspection using the traditional paper inspection process. There are two solutions to the issue; either find a method to perform the inspection faster and cheaper or to perform a more subjective inspection. The FAA has offered as an alternative to PCI, a less comprehensive pavement rating system called PASSER that is more subjective. However, it does not provide a pavement engineer with as much information about the pavement condition as the PCI method. The PASSER pavement rating method has not been widely adopted.

The primary purpose of the distress evaluation portion of a pavement evaluation is to determine the pavement condition and provide data for analyses of the causes, remaining life and remediation of the distresses. In a traditional PCI inspection, data sheets are filled out documenting the type of distresses in the sample area including their density and severity. In MicroPAVER analyses, the distress data is only used to calculate a corrected deduct value and all the useful information of the distresses collected in the paper inspection sheets is filed away or discarded. Because geospatial information systems and the computers required to run them are very inexpensive, it is prudent to develop a pavement management system that captures and analyzes this valuable data.

DMJM Aviation developed a distress pavement data collection system that collects all the information that would be collected in a traditional PCI pavement inspection using GPS receivers and tabletPCs. The technology advantage is that GPS determines the location of the distresses, the data are collected faster, the data are collected directly into digital format and are never transcribed from field notes (a significant source of error) and the GIS visualization of the data provides a better quality review. A second technology advance is that once the data are collected they can be analyzed using geospatial analyses and a PCI can be calculated for 100% of the samples using the computer.

The DEN project selected a ruggedized tabletPC shown in Figure 1 that is marketed for constant field use and has a sunlight readable screen. The specific model was chosen because it could be fitted with an integrated Wide Area Augmentation System (WAAS) capable GPS that attaches directly to and communicates directly with the tabletPC. Other models of tabletPCs that were less rugged and used Bluetooth for GPS communication were considered as they had been used successfully on other airport pavement evaluations. However, because of the large amount of pavement to rate and time frame in which to rate the pavements, the ruggedized tabletPCs were considered wise investments in productivity.

Figure 1. Ruggedized TabletPC and integrated GPS used at DEN.

The tabletPCs were configured with ESRI ArcPAD version 7.0 software that was customized for the pavement evaluation function. Customization allowed for pull down menus for each distress type, distress severity, and inspector by name. The data collection screen also included date and a comment field that could be written using a stylus in the field. The project team has adopted the pavement distress identification of the military as written in current manuals including the numbering of distress types [6].

However, a local modification of the severity of map cracking/crazing distress was made to better analyze the cause and progression of map cracking at DEN. In both ASTM D-5280 and in the UFC 3-270-5, map cracking is low severity until actual scaling of the concrete takes place for medium and high severity. In order to study concrete durability problems more thoroughly, map cracking was rated on a scale of 1 to 7 rather than low, medium and high severity. At most commercial service airports when map cracking reaches the point of medium or high severity, it would already have been replaced because scaling of the concrete would be unacceptable for foreign object debris potential. Rating levels 6 and 7 of map cracking are identical to medium and high severity scaling in the UFC 3-270-05. For DEN, rating levels 1 to 5 were differentiated due the size of map cracking, width of map cracking, and percent of the slab that had map cracking. Training of pavement raters was carried out to differentiate levels of map cracking from shrinkage cracking and durability cracking, which are all very similar. However, the accuracy in identifying the distresses was critical to the pavement evaluation at DEN and the data were used to select areas for core samples.

The project schedule at Denver International Airport was negotiated to conduct the distress mapping on 100% of the airfield pavements during the summer of 2006. Additionally, runways and associated taxiways would be scheduled for closure for maintenance during a window from noon to 3 pm daily as dictated by DEN Operations and the FAA tower. The scheduled closures would be altered for maintenance activities or weather conditions at a moments notice. No special daytime runway closures were allowed to conduct this distress mapping and all surveys had to be conducted during these standard closure times or be conducted on a basis in which the raters would give way to taxiing aircraft. The entire terminal apron inspection was conducted on a give way to taxiing aircraft basis and constituted a major portion of the rating time requirements.

The compressed time schedule, the short runway closure time windows, and the requirement to always be flexible resulted in selecting a potential crew rating size of up to 8 raters at a given time. DEN has six runways; one constructed in 2003 is 16,000 feet long and 200 feet wide. The original five runways that were constructed in 1992 and 1993 are 12,000 feet long and 150 feet wide. Four runways are eight slabs of 18.75 feet in width and one runway is 6 slabs of 25 feet in width. A survey crew of 8 could walk along a runway with one rater per slab lane observing 100% of the distresses. Therefore, eight tabletPCs and eight GPS capable camera were acquired for this project. However, on any given day a typical pavement crew as shown in Figure 2 consisted of 3 to 6 raters.

The surveying crew of multiple pavement raters was very successful and the speed of pavement rating was much higher than was projected at the beginning of the project. On the very first day of pavement rating, a six person crew was able to rate 6,000 feet of Runway 17L-35R during 2.5 hour runway closure because the runway was six slabs wide. The speed, or production rate, is also dependent upon the number and consistency of the distresses on the pavement and the number of photographs taken while rating the pavement. The newest runway had hardly any distress and, therefore, a six person crew was able to rate the pavements and map the distresses on the entire 16,000 foot runway, 200 feet wide in a single 3 hour runway closure.

Figure 2. A Typical Daily Pavement Rating Crew at DEN.

A full time engineer was the responsible crew leader. The pavement rating crew was composed of engineering students from local universities working as interns. The civil engineering students were productive workers and were eager to accept the new technology of the GPS cameras and the tabletPCs. The students helped refine the data collection software to make it more productive and helped in the QC effort. Daily inspections from each tabletPC were backed up to a central location after each inspection day.

The entire pavement distress mapping was completed in less than 3 months. The runways and major taxiways were 90% completed in the first month as priority was given to completing these areas because of the short duration closure windows. The crew size was reduced after the first month and one person was assigned a task of using the tabletPC to collect data from archived construction documents. The aircraft parking aprons took longer to complete and required some coordination with the airline operations managers. Actual production time spent in the field rating pavements varied daily from 3 to 6 hours and crew size varied from 3 to 6 pavement raters. The overall production rate resulted in the work accomplished faster than planned with a smaller size crew than planned. Because the production rate was so good, the critical path to complete the project shifted from distress mapping to pavement coring and petrographic analysis of cores.

Georeferenced Photography

In addition to pavement rating, the survey crewmembers were also responsible for taking GPS enabled photographs of distresses. The rating crews were equipped with Ricoh Caplio Pro 3 digital cameras as shown in Figure 3 with a WAAS compatible GPS in a compact flashcard. The instructions were not that every slab or every distress was worthy of photographs, but a photo should be taken of anything different or unusual. Photography was also requested of areas of map cracking as it was a areas of special emphasis..

Figure 3. Digital Camera with GPS attached.

Approximately 6,800 photographs of distresses are in the DEN database. In retrospect, a larger photo database would have enhanced the product. The photographs are very useful when you have sufficient coverage. The photographs coupled with the distress areas work very well together. During the analyses period and when selecting areas for further coring for petrographic analyses the GPS imbedded photographs coupled with the GIS distress maps were a huge time savings. It really saves a second trip to look at what is happening when the photograph and the pavement rating can be reviewed together in the GIS software.

Figure 4 shows a screen capture of the DEN GAPEMS GIS system with distresses, areas of deicing, and both a thumbnail version and popup window of a georeferenced photograph of a small patch on the taxiway centerline. To provide a scale reference, each rater also carried a 6-inch metal rule to be inserted into the photographs of the pavement distresses. Some raters chose to tie a sting to the 6-inch metal rule to speed production by throwing down the rule, taking the photographs and reeling in the metal rule by the string to go to the next pavement location. The

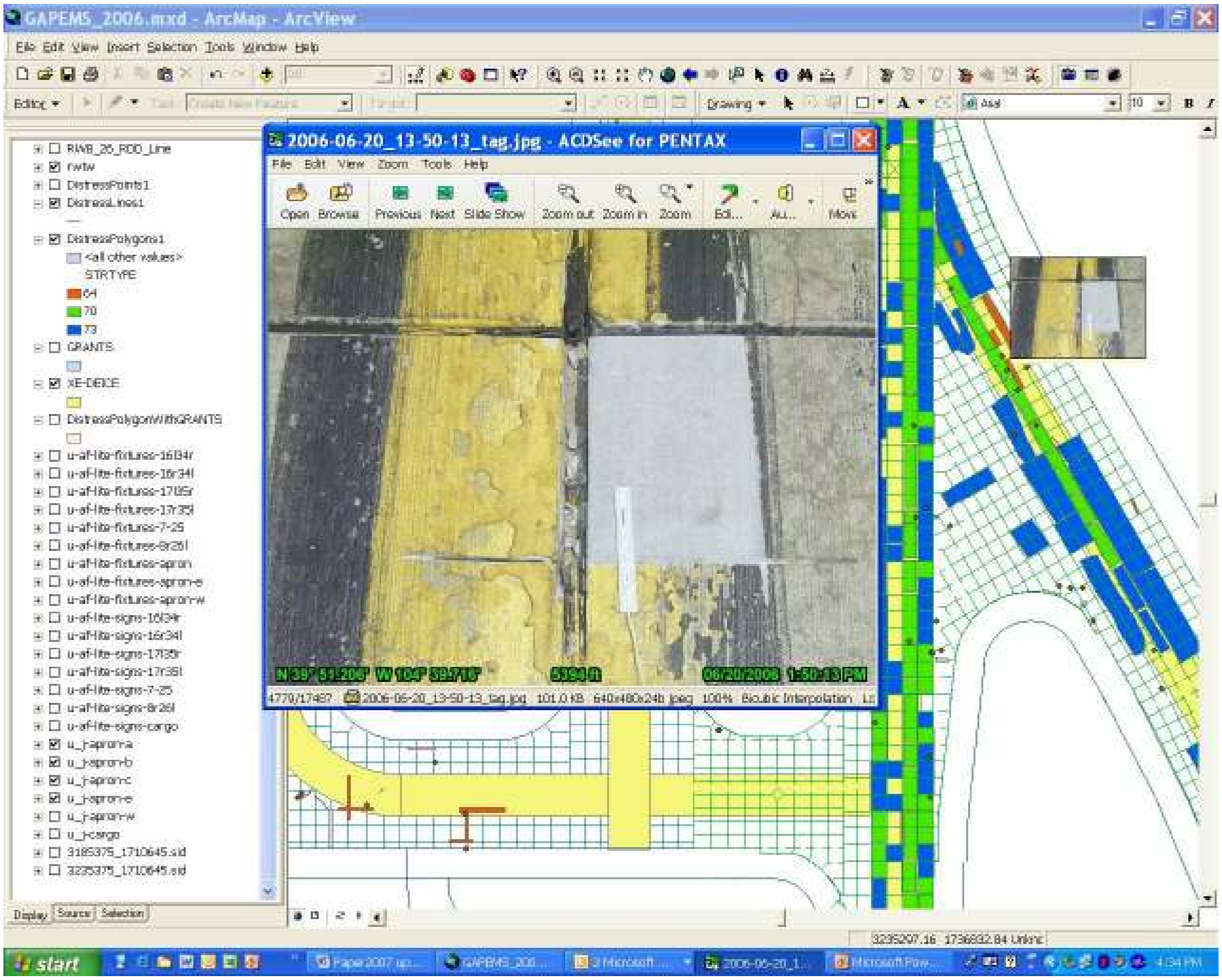

Figure 4. Screen Capture of GAPEMS showing georeferenced photography.

GeoLink software was configured to allow photographs to be imprinted with geographic coordinates, GPS measured altitude, and date and time of photograph.

Georeferenced Construction History

Denver International Airport was constructed in 1992 and 1993 as a green field site with five runways, taxiways, three concourse aprons, and a cargo apron. The concrete pavement was constructed by five different contractors each with their own onsite concrete batching plants. As with all FAA funded pavement construction projects, each project was required to submit FAA documents to close out the grant application through the submission of the Final Report. These closeout documents included daily inspection reports and other technical information about the mix design and cement certifications. These closeout documents were stored at the airport in paper form and provided useful information about the construction history of the airport pavements.

As part of the pavement evaluation, DMJM Aviation was interested in the weather conditions for the actual day that the concrete was placed, the mix design, aggregate source, and the curing method for every piece of concrete pavement constructed. From the closeout documents we were able to retrieve this information for about 90% of the pavements. The information to be collected from the closeout documents was to be analyzed in GIS format with other geospatial data. Therefore, it was determined that the tabletPC using ArcPAD software could be used to record this information directly into GIS and skipping the paper step. The ArcPAD software was modified in a similar manner to the GAPEMS distress data collection specifically for grant information data collection.

The data collection process was developed into a procedure in which one of the civil engineering students spent one month in the data archive room and transcribed the data onto a tabletPC. Using daily reports and stationing maps, the recorder would draw a polygon of the areas that were poured each day. The polygons would then be attributed with the name of the contractor, whether it was a hand pour or used a slip form paver, the date, the contract number, the mix design, and any comments. The data collected represented 3,600 polygons of separate construction concrete pours from five contractors and included the information from the 2003 construction of Runway 16R-34L. Figure 5 shows the cumulative millions of square feet of concrete construction by date for the unidentified five contractors.

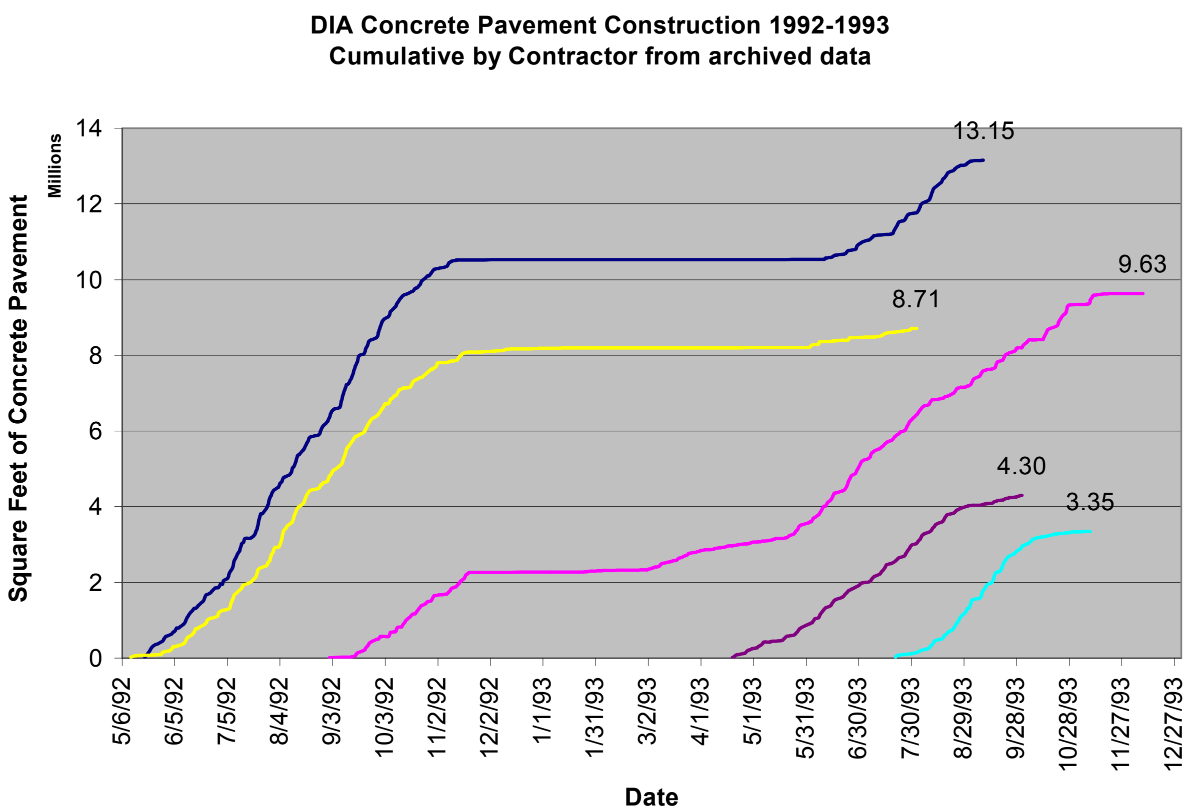

Figure 5. Graph of Cumulative Area of Construction by Date and Contractor.

The construction data is being analyzed using the HIPERPAV software program developed for the Federal Highway Administration (FHWA). The software analyzes the likelihood of plastic shrinkage cracking and thermal cracking using weather data from cloud cover, wind speed, relative humidity and temperature, and concrete mix design information. The software also calculates the evaporation rate in the first 8 hours of placement.

The distress data collected shows there is a definite pattern of shrinkage cracking and map cracking that is relative to specific days of construction. Certain days had very high numbers of slabs with observed shrinkage cracking. The data show that two construction days each had 201 slabs placed that now show shrinkage cracking. Figure 6 shows a graph of the number of distress polygons in the GIS database based upon the month of construction for map cracking, shrinkage cracking and durability cracking.

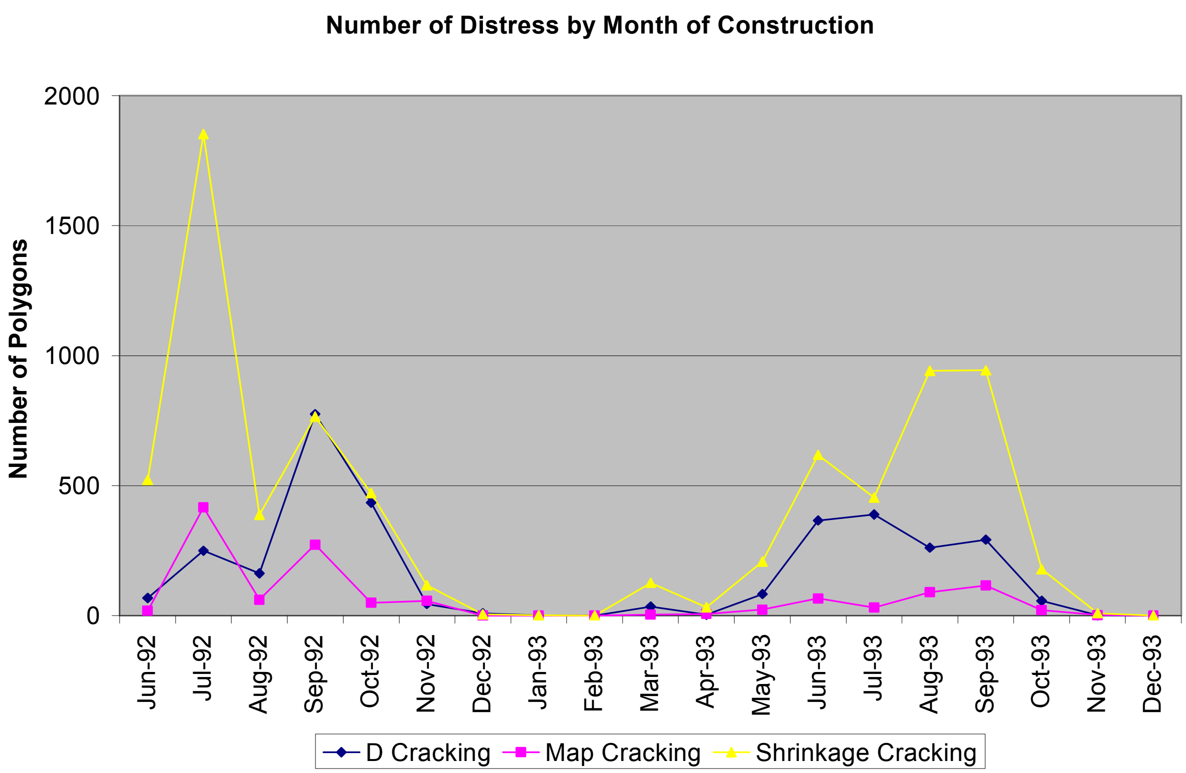

Figure 6. Analysis of Number of Distresses by Month of Construction.

Georeferenced Nondestructive Deflection Testing

As part of the pavement evaluation and pavement management system, all of the concrete pavement areas were analyzed for structural capacity using deflection testing. The traditional method of deflection testing as described in the FAA Advisory Circular is accomplished using a heavy falling weight deflectometer (HWD).[7] The HWD deflection takes an impact deflection by dropping a weight at a discrete point. On average HWD deflections can be gathered at a rate of 200-300 points in one night of testing. The HWD was used on a limited basis with about 2 weeks of testing.

However, the Rolling Dynamic Deflectometer (RDD), developed by The University of Texas at Austin, provides an alternative method of structural analysis and many more data points by taking deflection measurements continuously. The method was first used to evaluate commercial service airports at Dallas/Fort Worth International Airport and the ability to graphically show the deflections in GIS was first accomplished for Seattle-Tacoma International Airport as reported by James Bay [8, 9].

A very comprehensive deflection testing program was completed for this project. In addition to the two weeks of HWD testing, all of the runways, parallel taxiways, and high speed exit taxiways received multiple lanes of continuous deflection testing using the Rolling Dynamic Deflectometer. Over 125 miles of continuous deflection testing was accomplished with the RDD in 29 nights of testing. The test data represent the analyses of over 351,000 individual test points. The equivalent number of deflection points would be approximately equal to 4 to 5 years of HWD testing.

The technology advantage is that the whole 125 miles of deflection data can be graphically visualized and compared to any portion of the airport by zooming into the location in the GAPEM pavement management system. Figure 7 is a screen capture of the RDD deflections as shown in the GIS for Runway 17R-35L and an inset photograph of the RDD collecting data at a another airport in daylight.

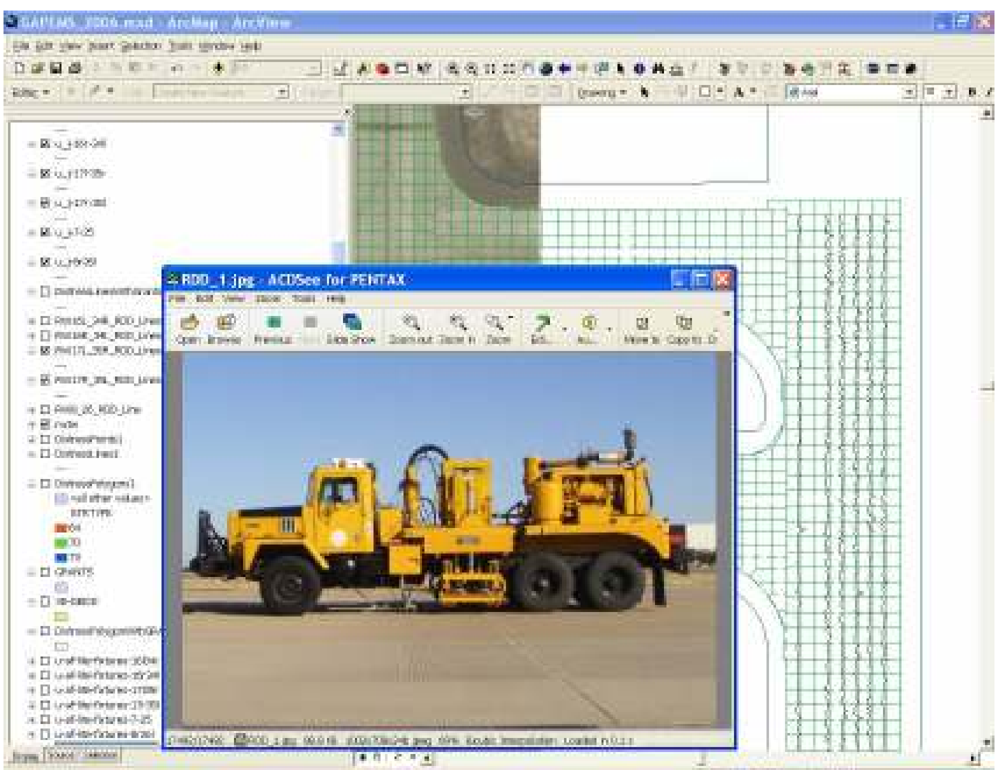

Figure 7. Screen Capture of GAPEMS GIS showing RDD and RDD Deflections at DEN.

Georeferenced Core Samples

A major portion of the pavement evaluation at DEN is the determination of the remaining life of the concrete pavement with respect to concrete durability in the harsh freeze-thaw and runway deicing environment at DEN. The pavement evaluation plan includes making determinations on approximately 200 core samples with petrographic analyses or special testing. Core sampling and petrographic testing was a critical path item in the project schedule and in order to maintain the necessary schedule, four separate petrographers were engaged.

GIS and tabletPCs were used in several new and unique ways during this project. First, the location of the cores were selected based upon the data collected with the tabletPCs for distresses of map cracking, shrinkage cracking and durability cracking. Some cores were selected in the field using the tabletPC to locate the cores based upon field observations. Other cores were selected in the office based upon distribution of distresses observed in the database of distresses.

The tabletPCs were used to coordinate the review of underground utilities prior coring the pavement section. This reduced the time to get the necessary clearance for a specific area by the senior electrical inspector for the airfield. After reviewing the data for the in-pavement light fixtures, also on the tabletPC, and other electrical systems, also on the tabletPC, along with his institutional knowledge, each core site was either cleared or moved to a new location on the spot. Marking was accomplished with paint.

Finally, the tablets were used for coring operations by the airfield escort of the coring operator to locate cores and track each core by assigned number. Each core was assigned a number and the number was written on the core in the field as soon as it was dry enough. Cores were then wrapped in plastic wrap and stored for shipment to the four petrographers used during the project.

In the office, the results of the core testing are added to the GIS database after receiving the test reports. The test report number, which references the comprehensive lab reports, is then referenced in the database as well.

GEOSPATIAL TECHNOLOGIES IN PAVEMENT MANAGEMENT

The use of geospatial technologies in the pavement evaluation was probably the most comprehensive in terms of shear size and complexity of any airport in the world. All of the pavement evaluation data was either collected directly into GIS or was converted into data that can be visualized or accessed directly in the GAPEMS GIS pavement management system. The pavement evaluation is not yet complete.

Once a comprehensive remaining life analysis and remediation analyses have been completed using the GIS data, customized reporting will be developed using geospatial technologies. When the project is complete, any authorized person at the airport will be able to use a web browser to view all the data in the pavement management system, update the data, perform queries on the data, and print reports. A custom reporting function allows the user to print map books of pavement areas with any of the data layers displayed.

Ultimately, DMJM Aviation will provide DEN with a GIS data base and pavement management tool that will allow the airport engineering staff to estimate annual funding requirements for pavement maintenance, repair and replacement. Additionally they will be able to prioritize airfield related projects and the associated costs can be developed years in advance with confidence.

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